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Rastogi

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(54) **TASK SCHEDULING BASED ON DEPENDENCIES AND RESOURCES**

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(60) Provisional application No. 61/358,837, filed on Jun. 25, 2010.

(51) **Int. Cl.**

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G06F 9/50	(2006.01)
H04L 29/08	(2006.01)
G06F 9/48	(2006.01)

(52) **U.S. Cl.**
CPC ***G06F 9/5038*** (2013.01); ***G06F 9/4881*** (2013.01); ***H04L 29/08963*** (2013.01)

(58) **Field of Classification Search**
CPC G06F 9/5038; G06F 9/4881
See application file for complete search history.

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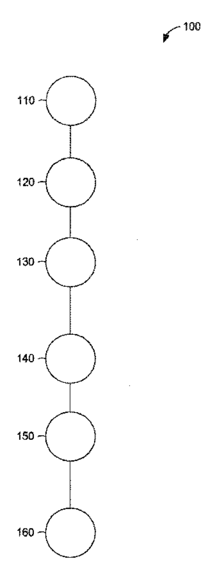
(57) **ABSTRACT**

An example system identifies a set of tasks as being designated for execution, and the set of tasks includes a first task and a second task. The example system accesses task dependency data that corresponds to the second task and indicates that the first task is to be executed prior to the second task. The example system, based on the task dependency data, generates a task dependency model of the set of tasks. The dependency model indicates that the first task is to be executed prior to the second task. The example system schedules an execution of the first task, which is scheduled to use a particular data processing resource. The scheduling is based on the dependency model.

14 Claims, 12 Drawing Sheets



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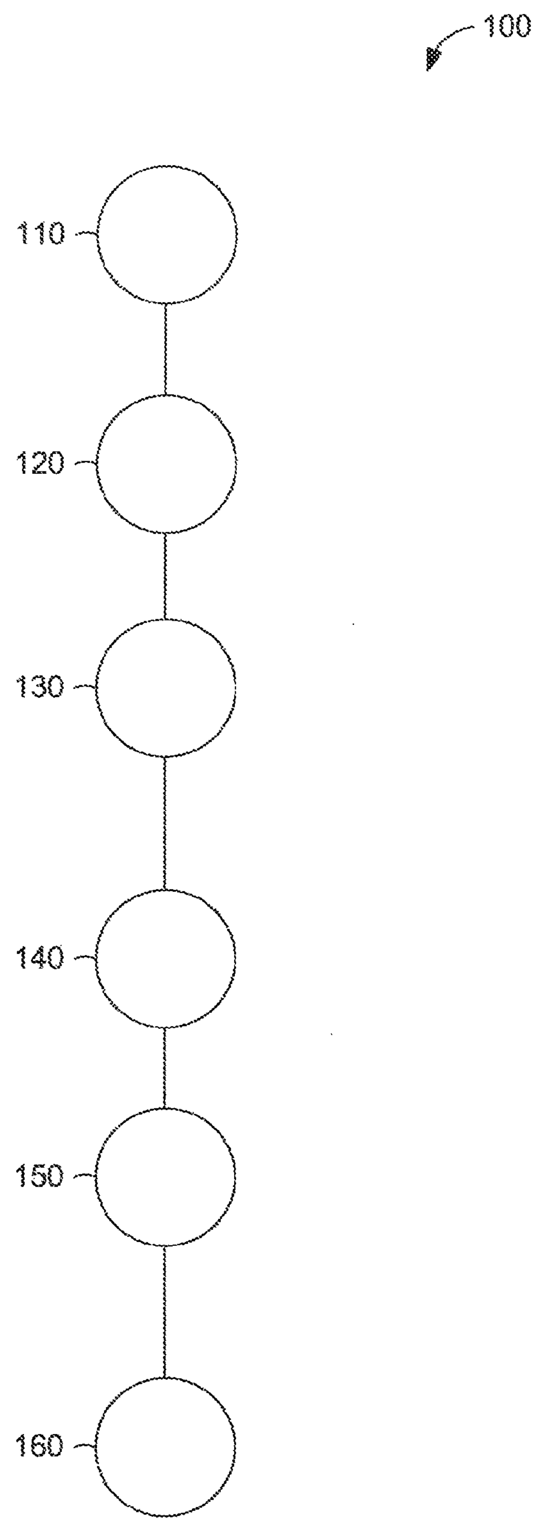


FIG. 1

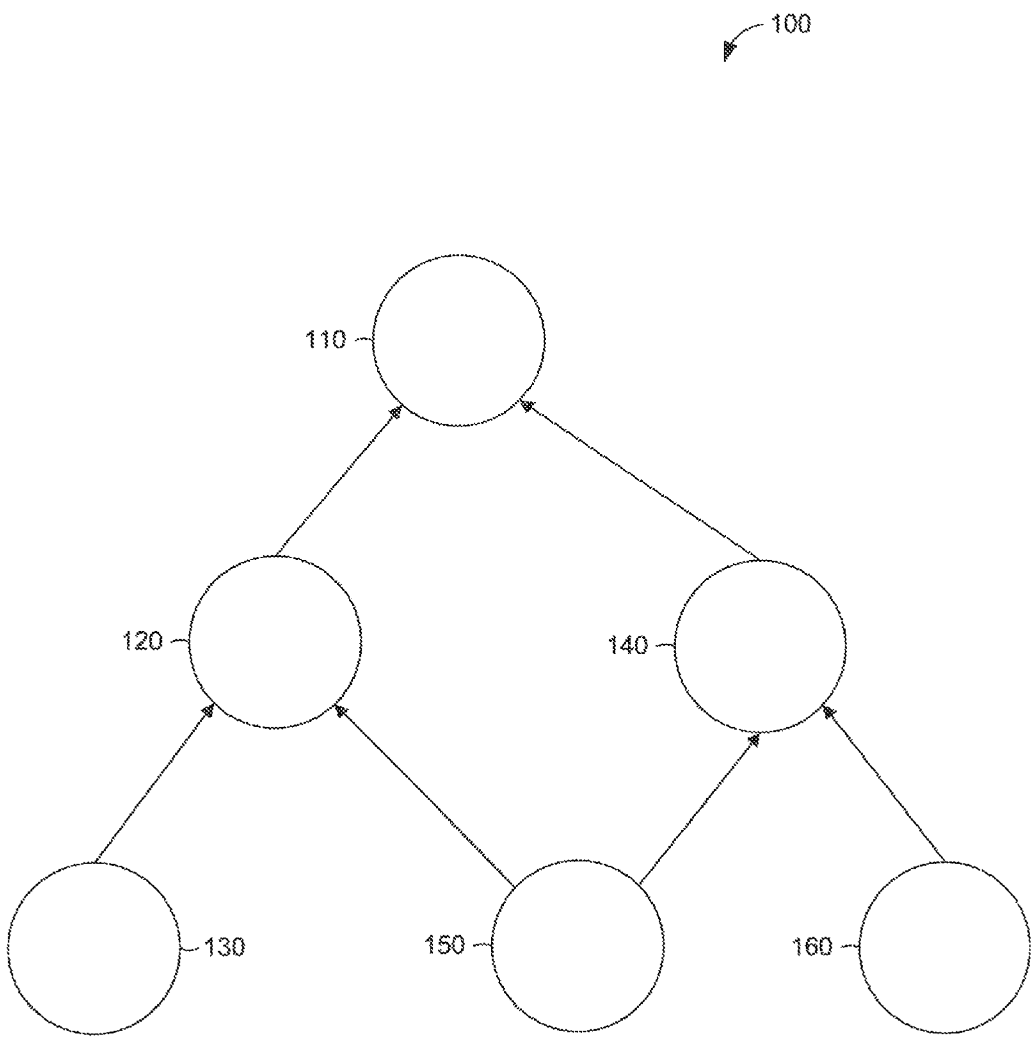
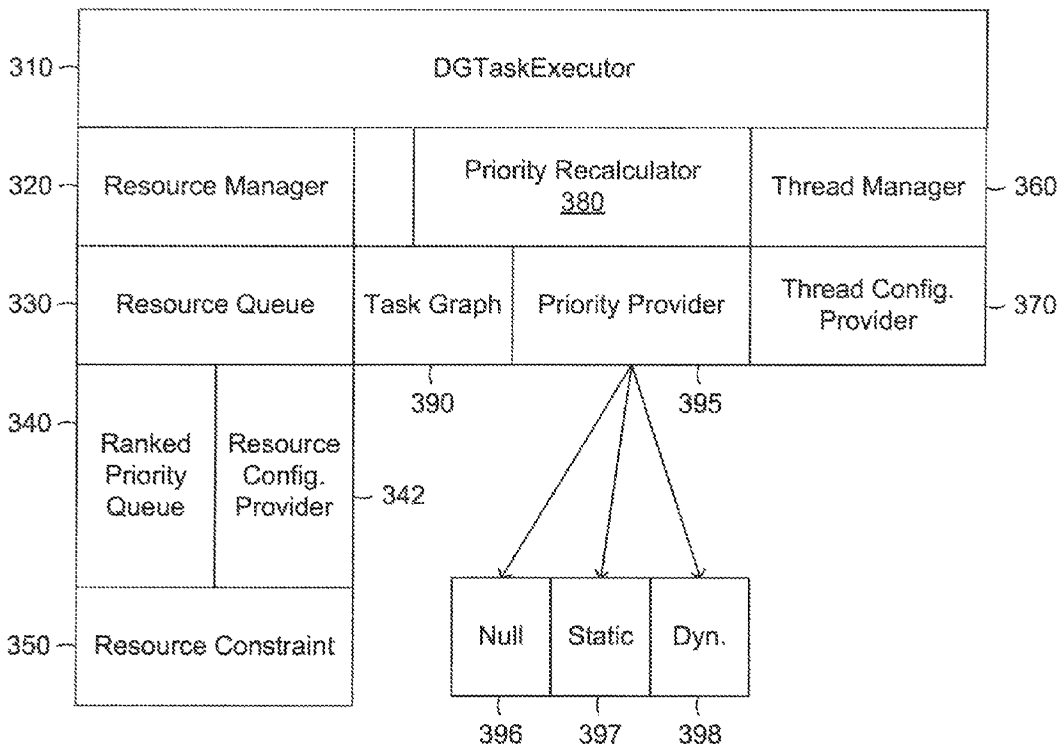


FIG. 2



310
DGTaskExecutor
320
Resource Manager
Priority Recalculator
380
Thread Manager
360
330
Resource Queue
Task Graph
Priority Provider
Thread Config. Provider
370
390
395
340
Ranked Priority Queue
Resource Config. Provider
342
Null
Static
Dyn.
350
Resource Constraint
396
397
398

FIG. 3

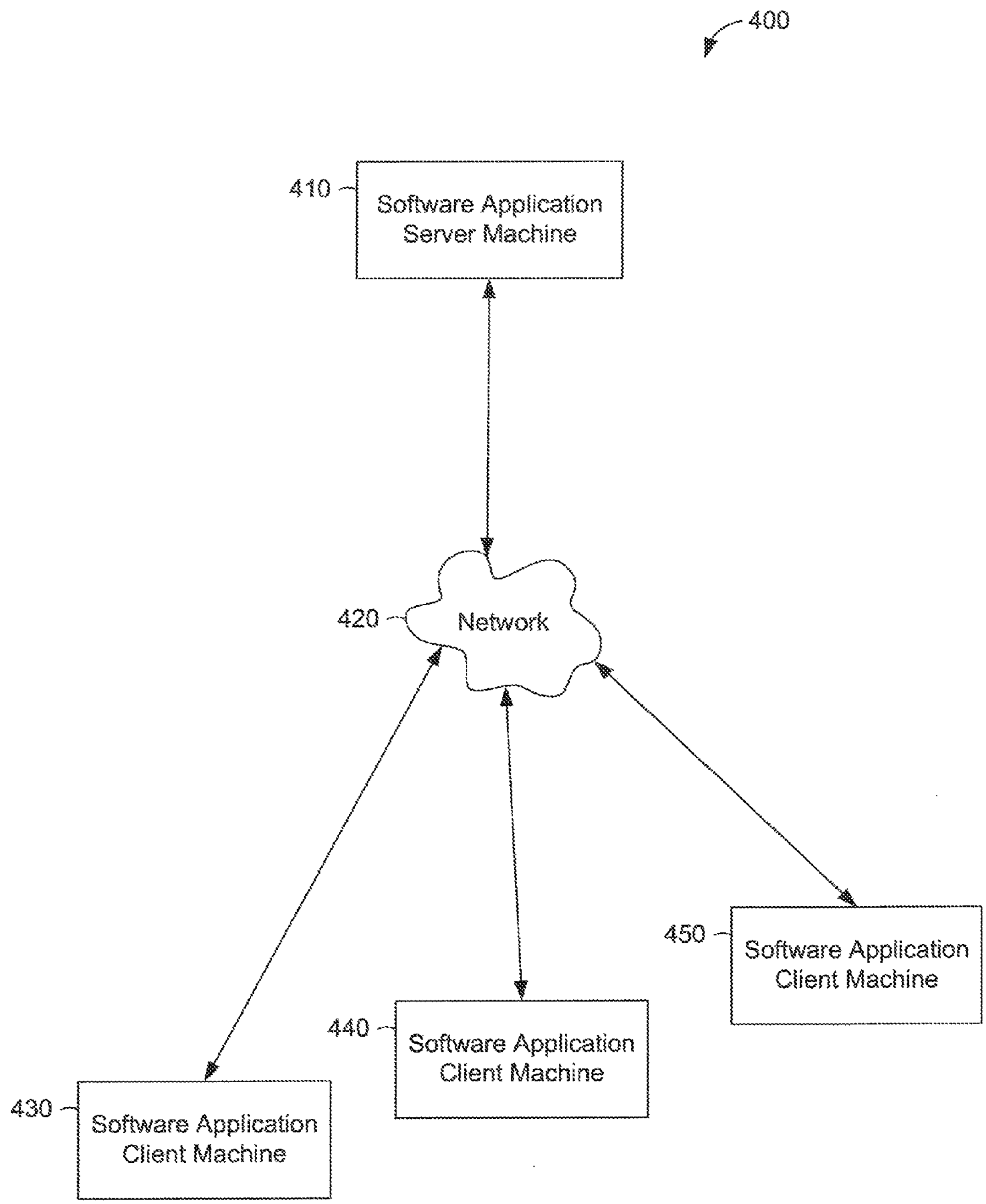
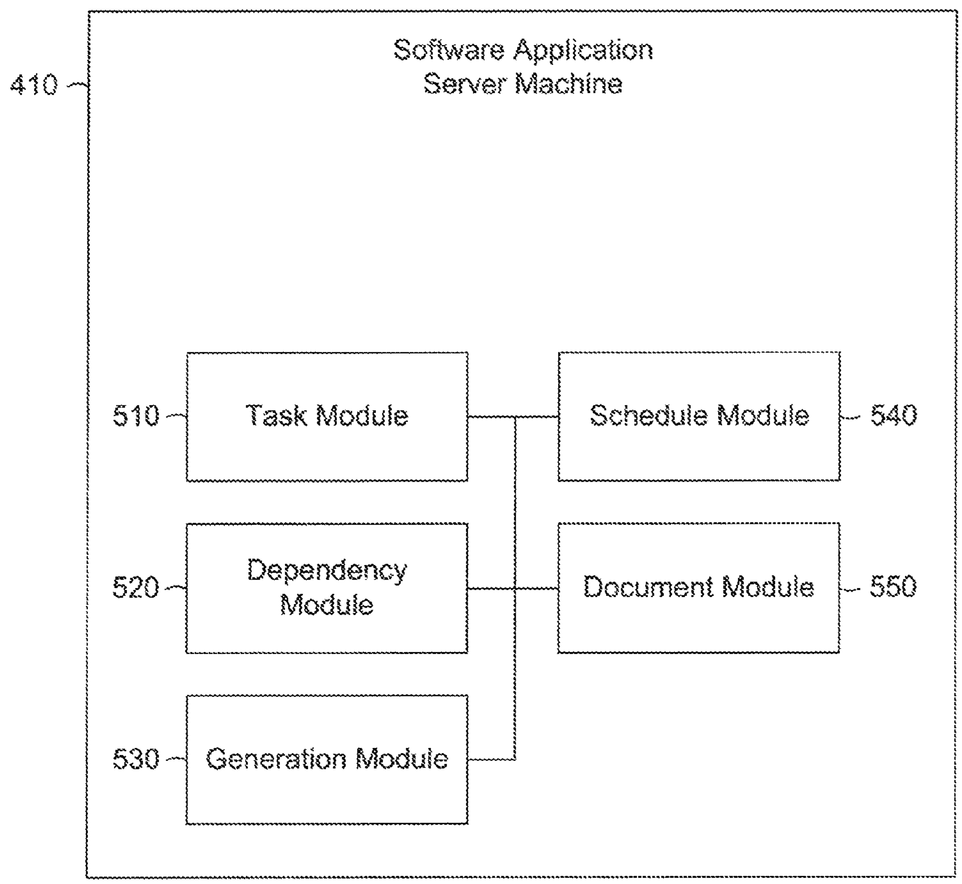

400
410
Software Application Server Machine
420
Network
450
Software Application Client Machine
440
Software Application Client Machine
430
Software Application Client Machine

FIG. 4



Software Application
Server Machine
410
510
Task Module
520
Dependency
Module
530
Generation Module
Schedule Module
540
Document Module
550

FIG. 5

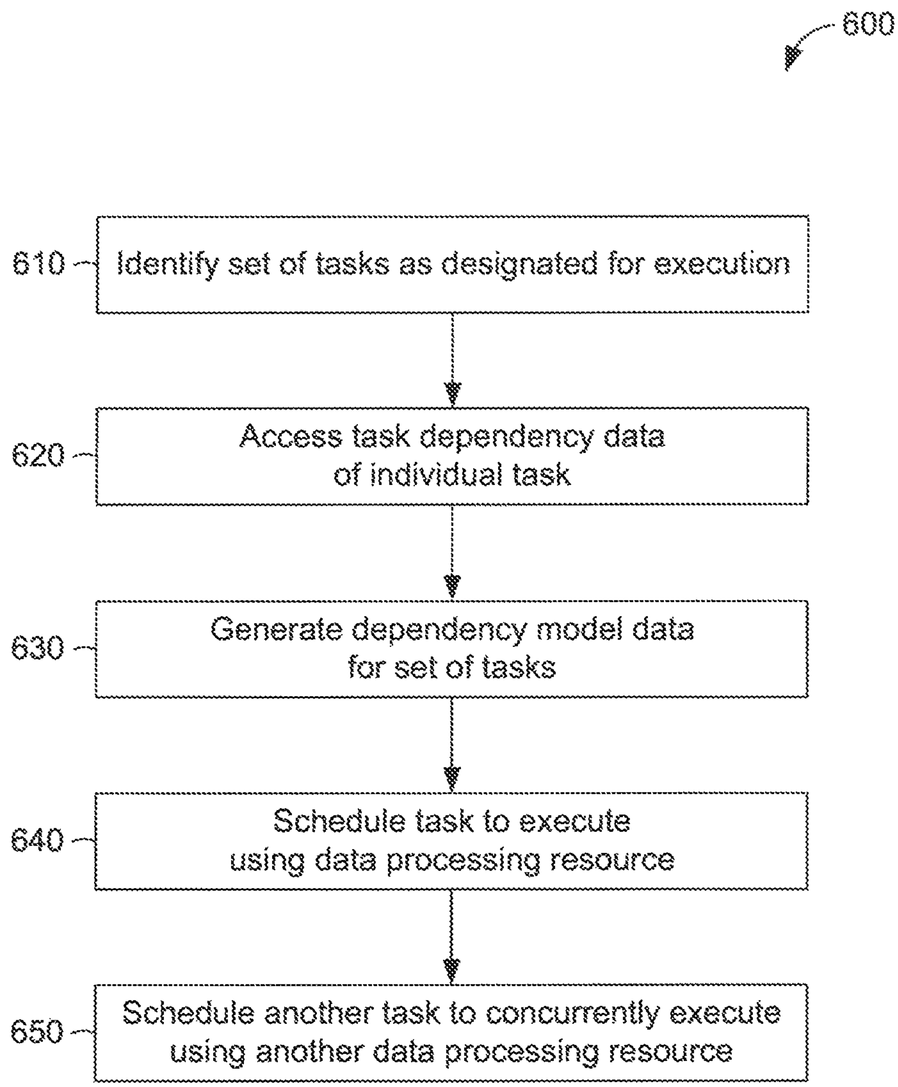

600
610
Identify set of tasks as designated for execution
620
Access task dependency data of individual task
630
Generate dependency model data for set of tasks
640
Schedule task to execute using data processing resource
650
Schedule another task to concurrently execute using another data processing resource

FIG. 6

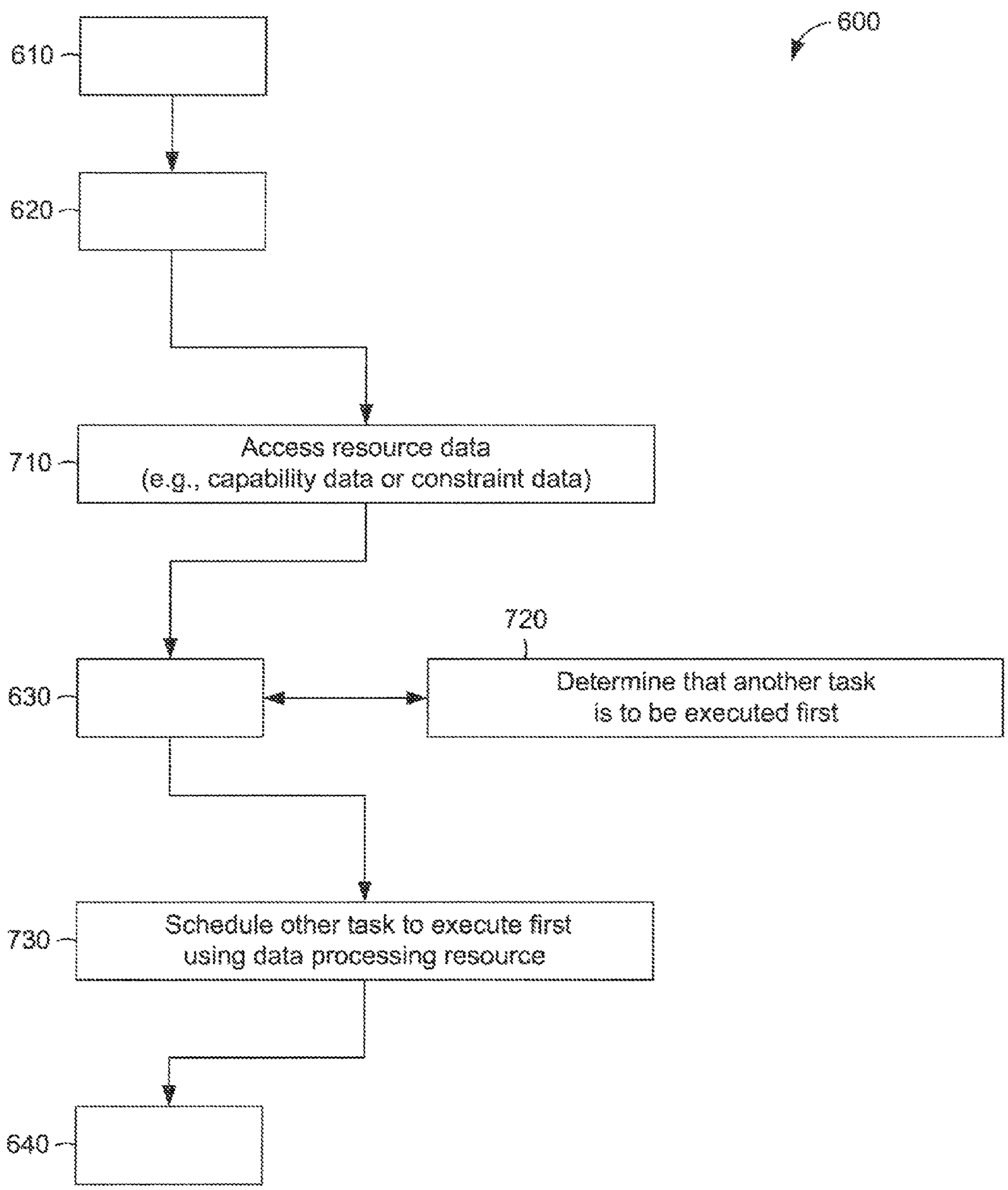

600
610
620
710
Access resource data
(e.g., capability data or constraint data)
720
630
Determine that another task
is to be executed first
730
Schedule other task to execute first
using data processing resource
640

FIG. 7

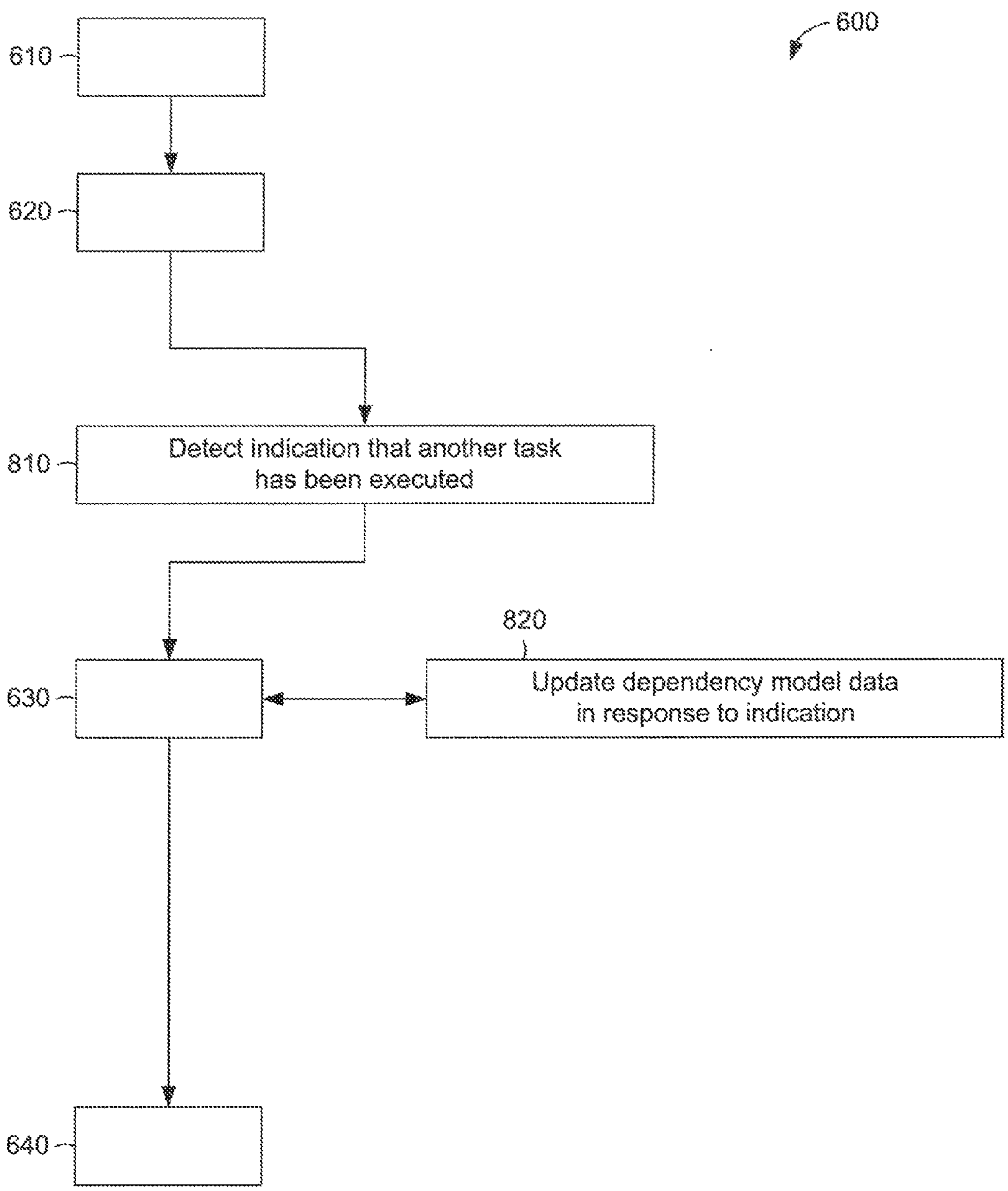

600
610
620
810
Detect indication that another task has been executed
820
630
Update dependency model data in response to indication
640

FIG. 8

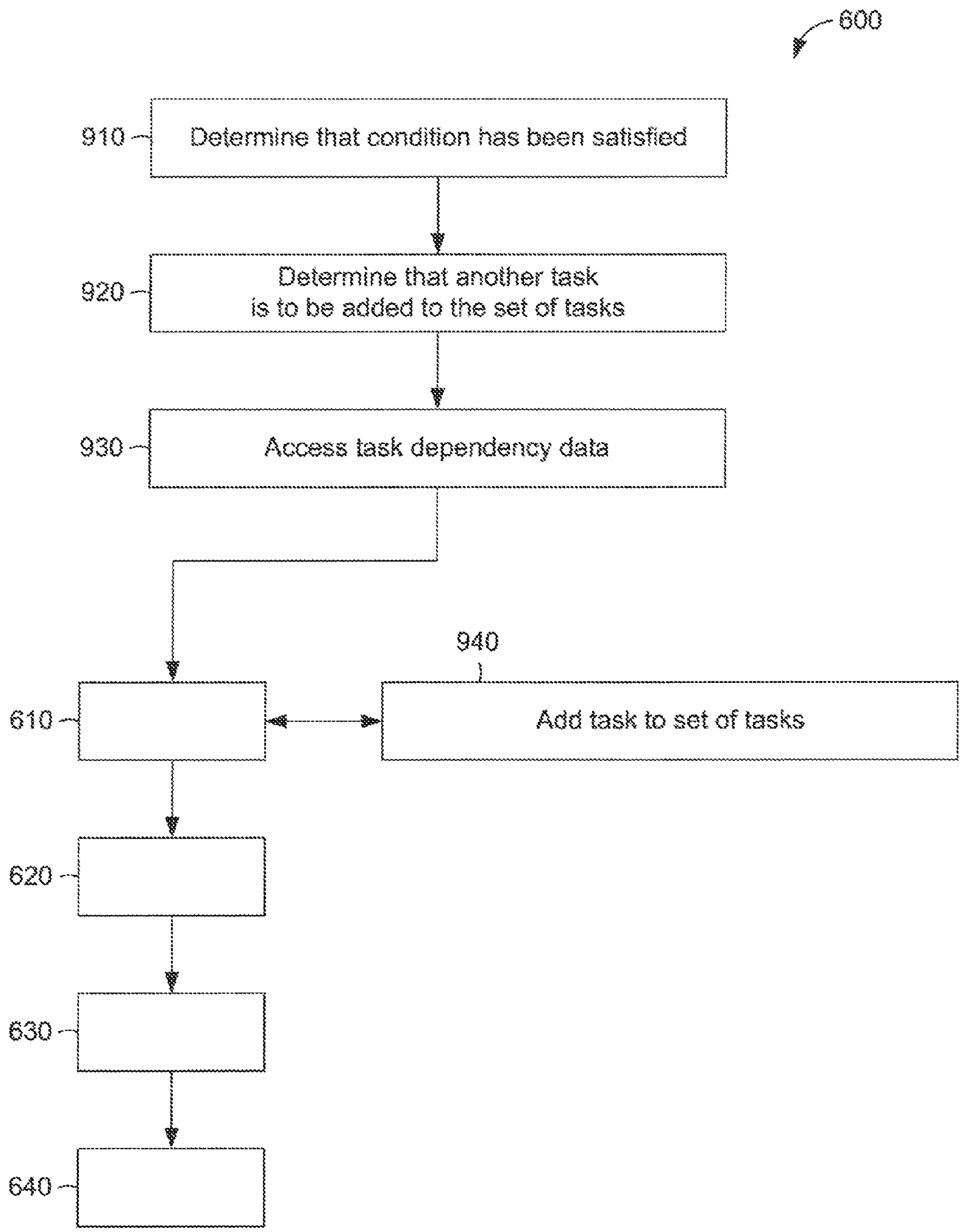

600
910
Determine that condition has been satisfied
920
Determine that another task
is to be added to the set of tasks
930
Access task dependency data
940
610
Add task to set of tasks
620
630
640

FIG. 9

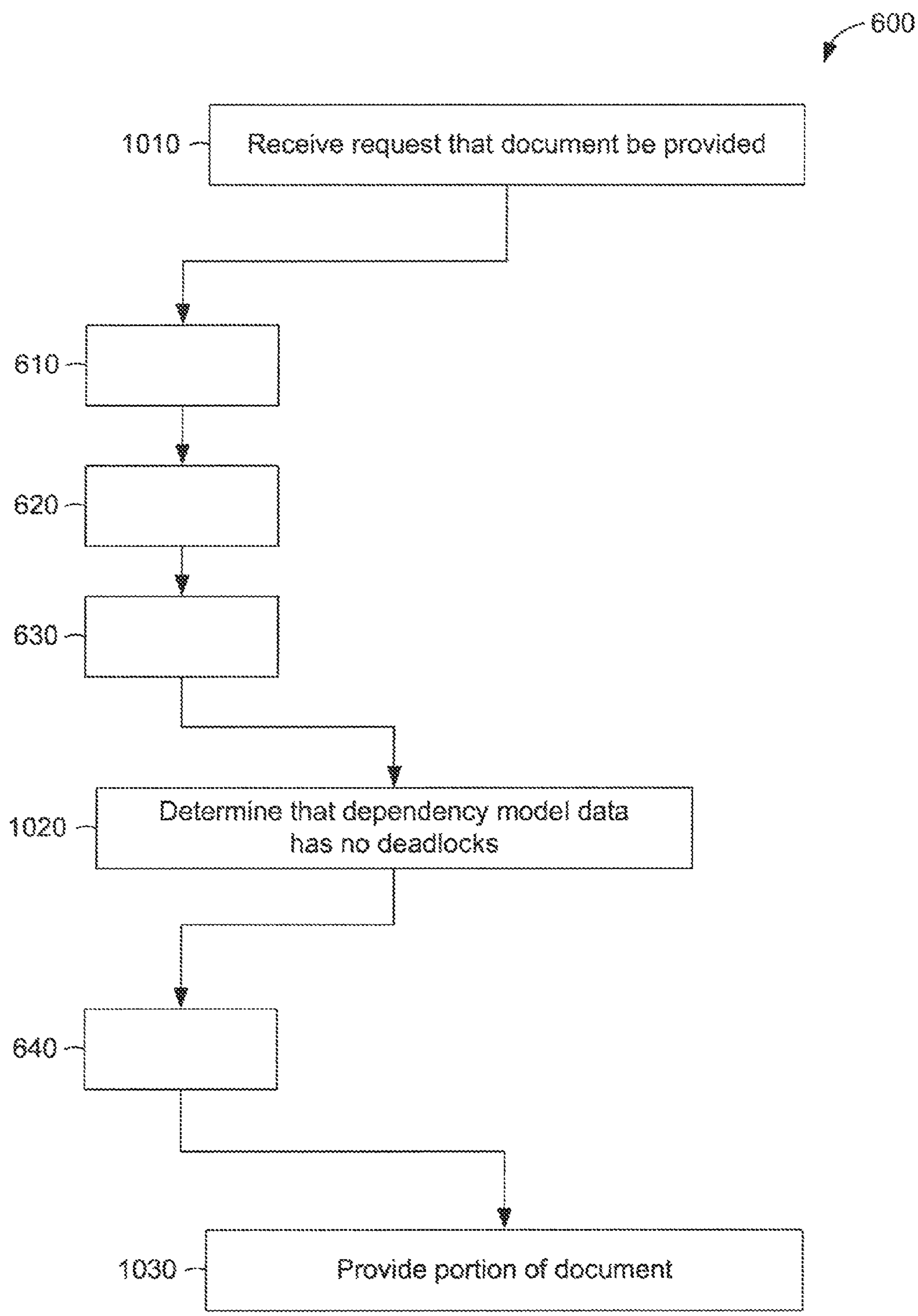

600
1010
Receive request that document be provided
610
620
630
1020
Determine that dependency model data has no deadlocks
640
1030
Provide portion of document

FIG. 10

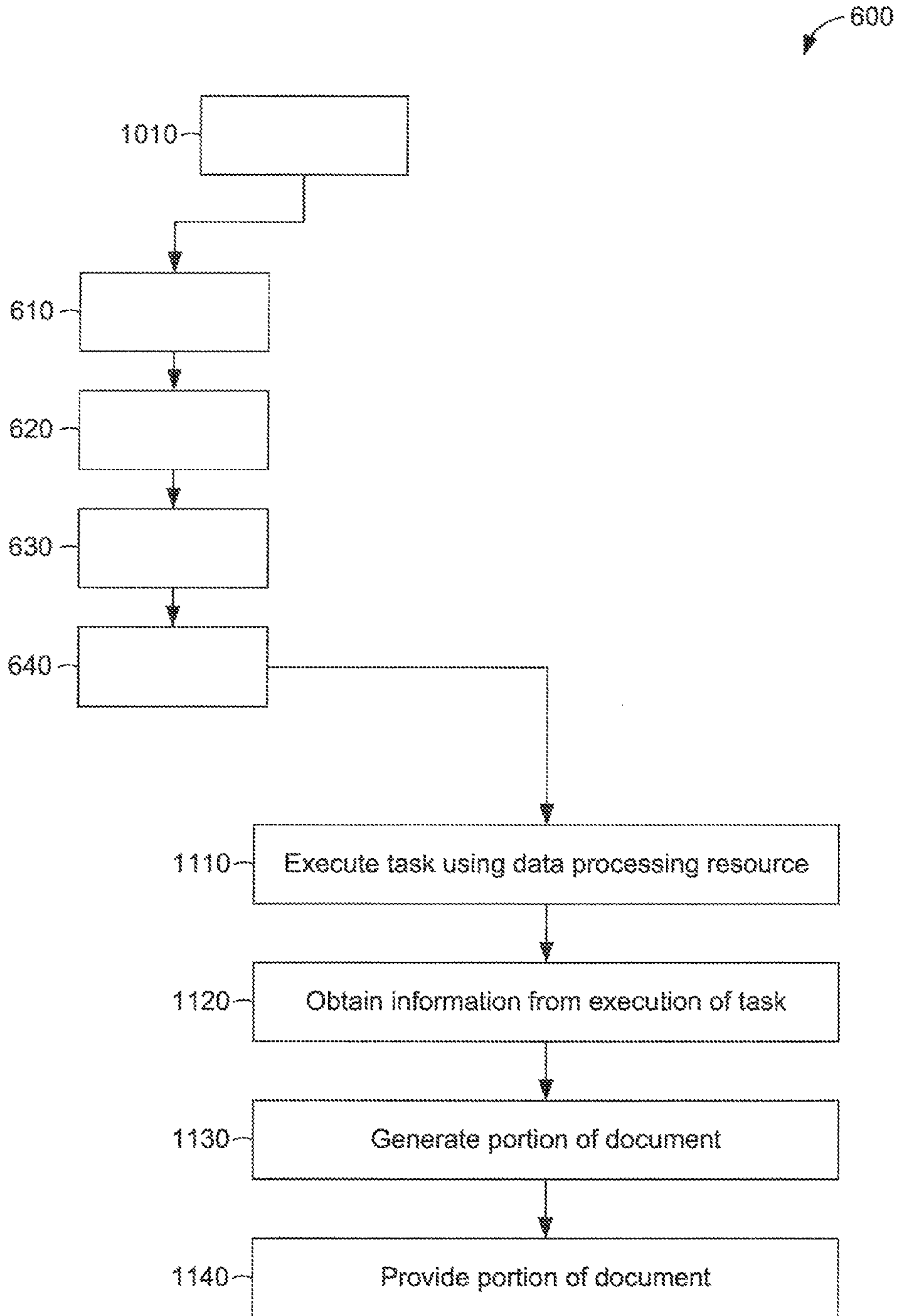

600
1010
610
620
630
640
1110
Execute task using data processing resource
1120
Obtain information from execution of task
1130
Generate portion of document
1140
Provide portion of document

FIG. 11

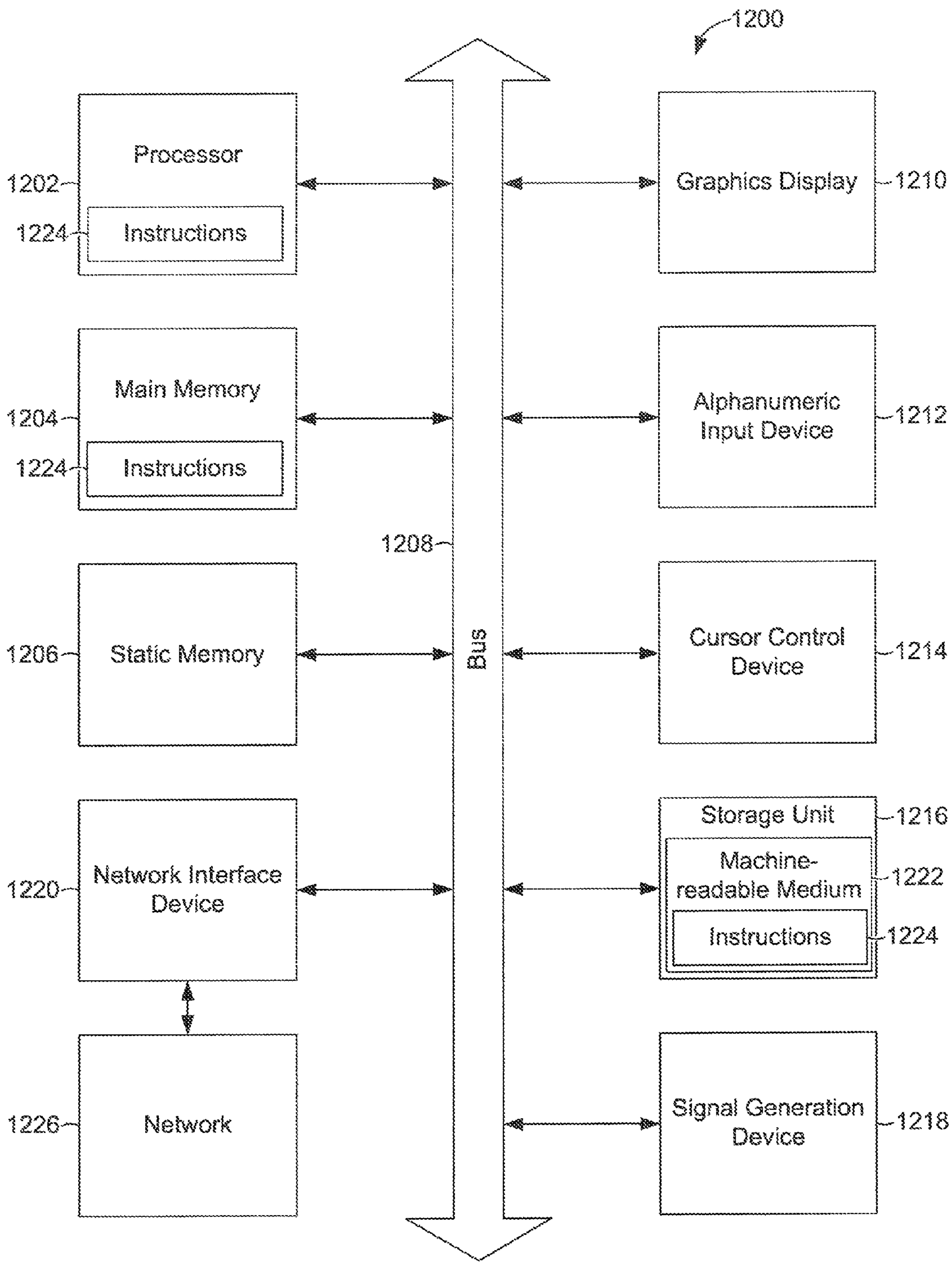

1200
Processor
1202
1224
Instructions
Main Memory
1204
1224
Instructions
1208
Static Memory
1206
Bus
Network Interface Device
1220
Network
1226
Graphics Display
1210
Alphanumeric Input Device
1212
Cursor Control Device
1214
Storage Unit
1216
Machine-readable Medium
1222
Instructions
1224
Signal Generation Device
1218

FIG. 12

TASK SCHEDULING BASED ON DEPENDENCIES AND RESOURCES

CROSS-RELATED APPLICATIONS

This application is a continuation of prior application Ser. No. 13/166,395, filed on Jun. 22, 2011, entitled "Task Scheduling Based on Dependencies and Resources," which claims the priority benefit of U.S. Provisional Application No. 61/358,837, filed Jun. 25, 2010, and entitled, "Task Scheduling Based on Dependencies and Resources." The entire content of each of the above applications is incorporated herein by reference.

TECHNICAL FIELD

The subject matter disclosed herein generally relates to the processing of data. Specifically, the present disclosure addresses systems and methods of task scheduling.

BACKGROUND

In data processing technology, software may include instructions to perform various tasks. As used herein, a "task" is a unit of work that may be scheduled for execution, either independently of other tasks or dependent upon one or more other tasks. Performance of a particular task may involve the use of a data processing resource. As used herein, a "data processing resource" is a tangible or intangible entity able to facilitate execution of the task. A data processing resource may include hardware (e.g., a processor, a memory location, or a peripheral device), software (e.g., a socket, a port, a device driver, or a network connection), or any suitable combination thereof.

BRIEF DESCRIPTION OF THE DRAWINGS

Some embodiments are illustrated by way of example and not limitation in the figures of the accompanying drawings in which:

FIG. **1** is a diagram illustrating an example of an execution schedule for a set of tasks, according to some example embodiments;

FIG. **2** is a diagram illustrating an alternative example of an execution schedule for the set of tasks, according to some example embodiments;

FIG. **3** is an architectural diagram illustrating data structures supporting DGTaskExecutor, according to some example embodiments;

FIG. **4** is a network diagram illustrating a network environment, according to some example embodiments;

FIG. **5** is a block diagram of a software application server machine, according to some example embodiments;

FIG. **6-11** are flowcharts illustrating operations in a method of dependency-based task scheduling, according to some example embodiments; and

FIG. **12** is a block diagram illustrating components of a machine, according to some example embodiments, able to read instructions from a machine-readable medium and perform any one or more of the methodologies discussed herein.

DETAILED DESCRIPTION

Example methods and systems are directed to task scheduling based on one or more dependencies and one or more resources. Examples merely typify possible variations. Unless explicitly stated otherwise, components and functions are optional and may be combined or subdivided, and operations may vary in sequence or be combined or subdivided. In the following description, for purposes of explanation, numerous specific details are set forth to provide a thorough understanding of example embodiments. It will be evident to one skilled in the art, however, that the present subject matter may be practiced without these specific details.

An example task scheduling system is referred to herein as "DGTaskExecutor" or "Directed Graph TaskExecutor." The example system is configured to perform one or more of the example methods discussed herein.

DGTaskExecutor may facilitate a determining of a set of tasks that can execute concurrently, management of one or more task priorities (e.g., scheduled execution times), management of one or more constraints on a data processing resource, or any suitable combination thereof. Figuratively, DGTaskExecutor may orchestrate how and when tasks will execute, for example, by dynamically assigning task priorities and utilizing (e.g., applying) resource constraints.

A software application (e.g., a web application) may entail one or more requests for execution of a set of tasks. In various example embodiments, execution of the software application causes the set of tasks to be requested for execution, designated as in need of execution, prescribed for execution, marked for execution, or otherwise identified as designated for execution. In some situations, two or more tasks within the set of tasks may be executable concurrently (e.g., in a multi-threaded implementation of the software application). In various situations, the set of tasks may include one or more individual tasks that, directly or indirectly, depend on another task. For example, a particular task may be unable to execute until another task has completed execution. As another example, a task may be unable to execute until another task has initiated execution, but may be executable any time thereafter.

DGTaskExecutor determines a priority of the task. For example, this determination may include inferring the priority of the task, scheduling the task for execution, or any suitable combination thereof. This determination may be based on one or more explicit or implicit constraints on a data processing resource to be utilized in executing the task. DGTaskExecutor therefore may facilitate concurrent execution of independent tasks using independent data processing resources. Moreover, a particular task may correspond to a particular set of constraints applicable to one or more data processing resources. Accordingly, DGTaskExecutor may dynamically adjust one or more task priorities (e.g., task schedules) as tasks are being executed, completing execution, or any suitable combination thereof. In some example embodiments, one or more constraints processed by DGTaskExecutor may be overridden (e.g., by custom data, user input, or data from the software application).

In facilitating the concurrent execution of two or more tasks, DGTaskExecutor enables a multi-threaded implementation of the software application. DGTaskExecutor allows the set of tasks (e.g., data defining the set) or a particular task (e.g., data defining the task) to configure a number of threads (e.g., additional threads beyond one thread) that will be used to process the set of tasks. According to some example embodiments, the set of tasks corresponds to work that may be performed by a server in processing a request for information identified by a network-based locator (e.g., a uniform resource locator (URL)). The set of tasks may correspond to a document to be provided (e.g., generated and communicated) in response to a request for the document. For example, a user may use a machine to access a URL, and a web server that serves the URL may respond by generating a document and providing the document to the machine (e.g., via a network). The generation of the document may involve (e.g., designate, request, prescribe, or mark) executing the set of tasks, that, when executed, obtain information that is usable to generate at least a portion of the document (e.g., one portion, multiple portions, or the entirety of the document).

DGTaskExecutor identifies a set of tasks as being designated for (e.g., requested for, prescribed for, marked for, or in need of) execution. For illustrative purposes, consider the set of tasks as including at least a first task and a second task (e.g., first and second tasks). DGTaskExecutor accesses task dependency data of the second task. The task dependency data may be accessed from a cache (e.g., to avoid runtime costs). The task dependency data of the second task corresponds to the second task and indicates that the first task is to be executed prior to the second task. DGTaskExecutor generates a dependency model (e.g., dependency model data) based on the task dependency data. The dependency model may be visualized as a graph or map depicting the tasks and the dependencies among the tasks. In particular, the dependency model indicates that the first task is to be executed prior to the second task. DGTaskExecutor then schedules an execution of the first task using a data processing resource. The scheduling of the execution is based on the dependency model (e.g., the dependency model data), and the execution of the first task is scheduled to occur prior to an execution of the second task. A dependency model may also be known as a "task graph" (e.g., a graph, diagram, or chart that illustrates dependencies among tasks).

DGTaskExecutor allows the user to dynamically change the execution pattern of an application by granting or removing access to data processing resources (e.g., processing threads) at runtime by modifying data processing resource profiles (e.g., a thread profile). A task graph may be generated at runtime. Accordingly, a task graph may represent a current "version" of the software application (e.g., application code), and as the software application changes over time, the task graph also changes. Generation of the task graph at runtime may have the effect of allowing DGTaskExecutor to dynamically optimize an execution plan for the set of tasks (e.g., as opposed to having a developer periodically optimize the execution plan manually).

FIG. **1** is a diagram illustrating an example of an execution schedule for a set **100** of tasks **110**, **120**, **130**, **140**, **150**, and **160**. The set **100** corresponds to a software application. For example, execution (e.g., invocation or initiation) of the software application may designate the set **100** for execution.

In the example shown, the tasks **110-160** are scheduled for sequential execution (e.g., one task at a time, one after the other). This is a single-threaded implementation of the set **100**. As shown, execution of the task **110** is to occur prior to execution of the task **120**, which is to occur prior to execution of the task **130**. Similarly, execution of the task **130** is to occur prior to execution of the task **140**, which is to occur prior to execution of the task **150**, which in turn is to occur prior to execution of the task **160**.

Some of the tasks **130**, **150**, and **160** may be significant tasks (e.g., primary tasks, critical tasks, or mandatory tasks) to be performed during execution of the software application. The other tasks **110**, **120**, and **140** may be tasks of lesser importance (e.g., secondary tasks, preparatory tasks, or optional tasks) that may be performed during execution of the software application.

In the example shown, the task **120** has a dependency upon the task **110**. In other words, the task **120** depends on completion of the task **110**, and proper execution of the task **120** requires that the task **110** be executed before the task **120**. Similarly, the task **130** depends on the task **120**; the task **140** depends on the task **110**; and each of the tasks **150** and **160** depends on the task **140**.

While the above-described dependencies are satisfied by the execution schedule shown in FIG. **1**, it is not necessary that, for example, the task **160** be executed after the task **150**. Rather, even though execution of the task **160** is scheduled to occur after execution of the task **150**, the task **160** is actually executable any time after execution of the task **140**, from which the task **160** depends, regardless of execution of the task **150**. Accordingly, execution of the tasks **110-160** may be parallelized to a significant degree in a multi-threaded implementation of the software application.

FIG. **2** is a diagram illustrating an alternative example of an execution schedule for the set **100** of the tasks **110-160**. In the example shown, the tasks **110-160** are scheduled for multi-threaded execution (e.g., execution of one or more tasks at a time). The task **110** is scheduled to be executed first. As noted above with respect to FIG. **1**, the tasks **120** and **140** each depend on the task **110**, but neither of task **120** or **140** is dependent upon the other. Hence, the tasks **120** and **140** may be scheduled for concurrent execution (e.g., parallelized execution), resulting in multi-threaded execution of the tasks **120** and **140**. According to various example embodiments, DGTaskExecutor implements an active form of concurrent execution, in which the tasks **120** and **140** are constrained to be executed fully or partially concurrently (e.g., their respective executions overlapping in time). For example, the tasks **120** and **140** may be scheduled in a synchronized manner to begin execution contemporaneously (e.g., at substantially the same time), to complete execution contemporaneously, or any suitable combination thereof. In certain example embodiments, DGTaskExecutor implements a passive form of concurrent execution, in which the tasks **120** and **140** are allowed to execute concurrently but are scheduled independently of one another.

Similarly, as noted above, the task **130** depends on the task **120**, and each of the tasks **150** and **160** depend on the task **140**. The task **150** has two dependencies; the task **150** depends on the task **120** and the task **140**. Accordingly, the task **130** is scheduled for execution any time after execution of the task **120**; the task **150** is scheduled for execution anytime after execution of the tasks **120** and **140**; and the task **160** is scheduled for execution anytime after execution of the task **140**. As shown, the tasks **130**, **150**, and **160** may be scheduled for concurrent execution, resulting in a multi-threaded execution of the tasks **130**, **150**, and **160**. As with the tasks **120** and **140**, concurrent execution of the tasks **130**, **150**, and **160** may be active or passive in form.

Returning to FIG. **1**, in a single-threaded implementation of the software application, one data processing resource is used at a time. Examples of the data processing resource include: a processor, a database (e.g., a connection to a database), and a service (e.g., a connection to a server to provide the service).

Returning to FIG. **2**, in a multi-threaded implementation of the software application, one or more data processing resources may be used at a time. As used herein, "multi-threaded" means fully or partially multi-threaded.

According to various example embodiments, the software application may specify one or more resource constraints (e.g., constraints on one or more data processing resources). Moreover, resource constraints may be specified by individual tasks corresponding to the software application. Furthermore, user input may be received and used to define one or more resource constraints.

In addition, DGTaskExecutor may allow the software application to configure a number of additional threads (e.g., processing threads beyond a single thread) to be used in processing the tasks of the software application. A data processing resource may have a thread profile (e.g., a resource-thread profile) that indicates a task execution pattern (e.g., a queue of scheduled tasks) for that data processing resource. DGTaskExecutor may adjust (e.g., update) the thread profile to optimize usage of the data processing resource. Based on the availability of resources, one or more of the DGTaskExecutor threads may select (e.g., configure a processor or other data processing resource to select) the highest priority task that can be executed. Tasks may be considered executable once all of their prerequisites have been completed. Once a thread has selected a task, the task may then be executed by the thread (e.g., using a processor configured by the thread) and the task may be no longer considered as executable.

An additional protection may be implemented the system to further avoid deadlock. Specifically, the DGTaskExecutor may be configured to complete once the last task finishes its execution (and no other tasks were made executable or are waiting for resources). This may be done regardless of the number of tasks that remain within the dependency model waiting for dependencies to complete. In some example embodiments, this situation can only arise if a deadlock missed being detected (e.g., because of a race condition). Regardless of cause, these "missed" tasks would not have been executed (e.g., because they are deadlocked). Therefore, in various example embodiments, the DGTaskExecutor may safely return and, in some cases, still guarantee that all of the executable workload assigned to the DGTaskExecutor was completed.

A developer of the software application may assign a task to a data processing resource. For example, the data processing resource may be identified by an enumerated value. The developer may assign the task to the enumerated value, and all tasks assigned to the enumerated value will share the same data processing resource and its resource constraints, if any.

Dependencies among tasks may be described in terms of "parent-child" relationships. For instance, where a second task is dependent upon (e.g., must be executed after) a first task, the second task may be described as a child of the first task, and the first task is a parent of the second task. Parent tasks may be described as prerequisites of a child task.

Prerequisites of a task may be static or dynamic. Static prerequisites are parent tasks that are known (e.g., identified in task dependency data) when a task is created or designated for execution. Dynamic prerequisites are parent tasks that are added after results from execution of the static prerequisites are known. For example, dynamic dependencies allow such parent tasks to be added after one or more of the static prerequisites have completed execution. As another example, a new parent task may be added in response to satisfaction of a condition (e.g., evaluated during execution of another parent task).

Similarly, a child task may be created at runtime (e.g., during execution of one or more tasks) and added to the set of tasks. In some example embodiments, execution of multiple software applications designates multiple sets of tasks for execution, and DGTaskExecutor may combine dependencies (e.g., multiple instances of task dependency data) together for task scheduling with shared threads, data processing resources, or constraints on the data processing resources.

DGTaskExecutor may also support joins (e.g., structured query language (SQL) join clauses). In some example embodiments DGTaskExecutor supports two types of joins, which allow for a task to wait for another task (or set of tasks) to complete.

Simple join tasks (e.g., joins) can be added as a synchronization point within a task graph. In some example embodiments, a DGTaskExecutor system may support join tasks that neither add nor impart any priority within the task graph. A task can also, at runtime, ask to join on an existing task. When this happens, the thread executing the task pauses execution of the currently executing task, and instead, executes other tasks until the join task has completed. Use of one or more join tasks may have the effect of avoiding a deadlock in which all threads in a system are waiting for some other join task to complete, but as all threads are waiting, there are no threads to do work. Moreover, the pause in execution may facilitate a performance optimization such that worker threads spend a minimum amount of time blocked (e.g., waiting for an available task).

DGTaskExecutor may also support the ability to pass data to tasks via a context. When initially adding a task to a dependency model (e.g., a dependency graph), a caller (e.g., calling function of a software application) may specify a context (e.g., a context object) that is to be passed to the task. Context objects may provide useful details from the software application that may be utilized during execution of a task or during determination of a set of prerequisites for a task. An example of a context object is a normalized set of inputs (e.g., input data) received with a web server request.

According to some example embodiments, task data (e.g., task dependency data) specifies a task identifier (e.g., Task ID) that uniquely identifies the task within DGTaskExecutor. For example, the task identifier may be an enumerated value. Task data may also specify a data processing resource to be utilized by the task, as well as one or more constraints on the data processing resource.

Task data (e.g., task configuration data) may specify an ability to constrain a number of concurrently executing tasks that may utilize a particular data processing resource. The task data may specify usage of the data processing resource as being unconstrained (e.g., unbounded). For example, lightweight business logic (e.g., aggregate results from subtasks) may utilize the data processing resource in an unconstrained matter. The task data may specify a constraint upon the usage of the data processing resource. Specifying a constraint may have the effect of limiting a maximum concurrent utilization of one or more data processing resources to a fixed (e.g., predetermined) number of concurrent executions. In various example embodiments, a fixed number of concurrent executions may have the effect of reducing a likelihood of overburdening the data processing resource when executing tasks (e.g., rendering three-dimensional models, processing large data sets, or other processor-intensive activities). The task data may specify that the task is not executable or otherwise will not impact the data processing resource. For example, a task may be utilized solely to orchestrate subtasks (e.g., joins), and the task therefore never actually utilizes the data processing resource. The task data may specify information (e.g., metadata) pertinent to the data processing resource. For example, where the data processing resource is a database, the task data may specify a logical host or tier of the database.

Task data may specify any number of prerequisites (e.g., a parent task) or no prerequisites, if none are needed. As noted above, a prerequisite may be static or dynamic. Taken together, static and dynamic prerequisites, if any, represent a minimum set of tasks required for a task to execute. Task data may specify a method that represents work to be accomplished by execution of the task, as well as information pertinent to handling of exceptions, errors, or results generated by the method.

DGTaskExecutor may also support an ability to save a result (e.g., store information resultant from the execution of a task). DGTaskExecutor may access (e.g., load) results from any task, and DGTaskExecutor may update (e.g., modify or clear) results from any task. Tasks may support the ability to save information for access by other tasks or the calling software application. If there is a need to garbage-collect the object early (e.g., before fully processing a software application), a method may also be provided by DGTaskExecutor.

DGTaskExecutor may also support runtime inspection or auto-deduping of tasks within a task graph. Deduping, as used herein, refers to identifying duplicate tasks. In various example embodiments, deduping includes inhibiting execution of one or more duplicate tasks (e.g., ignoring the task, removing the task, deleting the tasks, or preventing the task from executing).

DGTaskExecutor may also support detection of deadlocks (e.g., circular patterns of dependencies). According to some example embodiments, DGTaskExecutor avoids deadlocks, rather than prevents deadlocks. If a deadlock is detected, DGTaskExecutor may raise an exception and save a "safe" version of the dependency model. DGTaskExecutor may then proceed to execute the set of tasks to "completion," even if proceeding will result in one or more individual tasks being completed in an "error state."

When adding tasks to the dependency model (e.g., a dependency graph), DGTaskExecutor may use a lightweight algorithm to evaluate static prerequisites. When a task is added, DGTaskExecutor evaluates all of the new "static" prerequisite tasks to be added to expand the graph represented by this task and discover the set of previously unknown tasks that also need to be registered into the dependency model. This new set of tasks may then be sorted (e.g., by DGTaskExecutor) via topological sort so that the least dependent task will be added to the dependency model first. The now sorted list may be processed in order, and the DGTaskExecutor may ensure that for each new task added to the dependency model all of the prerequisites for the task are known (which may be guaranteed by the topological sort). Furthermore, DGTaskExecutor may ensure that all of the prerequisites are not in a deadlocked state already. In some example embodiments, deadlocks are detected if, for some reason, the validation shows that a prerequisite for a task was not registered before the task itself was registered, It is in this way that the DGTaskExecutor may guarantee that the dependency model is always in a safely executable state. If a task cannot be added to the dependency model (e.g., because one of its prerequisites was not created), a circular dependency pattern exists and may be detected by DGTaskExecutor In certain example embodiments, the final step of registration of a task in the dependency model is to rescore the model so that the task's priorities for the task itself and for its prerequisites properly model the importance of the task within the system. Rescoring may be implemented in various example embodiments so that the threads (e.g., data processing resources configured by the threads) select the most important task that is waiting to execute.

Existing tasks may not need evaluation in this algorithm, for example, because none of the existing tasks has a dependency on any of the new tasks that are being added to the dependency model. This may happen because DGTaskExecutor only adds previously unknown tasks to the dependency model. If that dependency had existed previously, the task is already in the dependency model, and as such, DGTaskExecutor would not need to add it.

For dynamic prerequisites and joins, a more complex and expensive algorithm may be used to detect deadlock. The algorithm evaluates whether any prerequisite tasks of the new dependency is dependent on the task adding the dynamic prerequisite or join. The algorithm may facilitate ensuring that, even with this new dynamic prerequisite, the dependency model is still safely executable, and that all of that task's children are able to execute. In the event that a deadlock is detected, all of the tasks that are dependent upon the task that is adding the dynamic dependency may be marked (e.g., by DGTaskExecutor in accordance with the algorithm) as failed within the graph.

The DGTaskExecutor may maintain a state machine for each task as it is being processed by the system. According to various example embodiments, the states in order are:

Initial State—this is a state of a task before it has been registered;

Static Prerequisite Registration—this is a state where the static prerequisites are expanded and registered within the dependency model;

Wait for static prerequisite completion—this state indicates that the task is waiting for the static prerequisites to complete;

Dynamic Prerequisite Registration—this is a state where the task can load data from static prerequisites, and then choose to register new tasks as dependencies;

Wait for dynamic prerequisite completion—this state indicates that the task is waiting for the dynamic prerequisites to complete;

Wait for resource availability to execute—once all prerequisites have completed, this state may be used to indicate that the task is to wait for resources to become available so that the task can execute and return a result;

Execute—this state indicates that the task performs the duties configured for it by the developer of the task; and

Completion—this state indicates that the task has finished executing and that the results or exceptions generated by the execution are available for loading by any dependent tasks. Additionally, in the Completion state, any dependent tasks whose prerequisites are now satisfied me be moved into the "Wait for resource availability to execute" state.

DGTaskExecutor may also support a sharing of data from a processing thread of a parent task with a processing thread of its child task. Examples of such data include ThreadLocal Cache and application context objects.

According to various example embodiments, execution of a task is dependent on results from its prerequisites, if any. Any exception, error, or results arising from execution of the task is made available by DGTaskExecutor to any other task that requests some or all of this information.

DGTaskExecutor may contain primary controls for generating a dependency model (e.g., dependency model data). The following method may be called with one or more tasks to be designated for execution:

```
public final class DGTaskExecutor
/*
    * executeAndWait
    *
    * This method will start executing the task (as well
    * as any other tasks within the task hierarchy) in
    * parallel.
    *
    * The calling thread will wait until the specified task
    * has executed and will return.
    */
```

-continued

```
public <ContextType> void executeAndWait(IDGTask<? super
ContextType> taskToExecute, ContextType taskContext)
/*
   * executeAndWait
   *
   * This method will start executing the specified tasks
   * (as well as any other tasks within the task
   * hierarchy) in parallel.
   *
   * The calling thread will wait until the specified task
   * has executed and will return.
   */
public <ContextType> void executeAndWait(BaseEnum
tasked, List<? extends IDGTask<? super ContextType>>
tasksToExecute, ContextType taskContext)
```

FIG. **3** is an architectural diagram illustrating data structures **310**, **320**, **330**, **340**, **342**, **350**, **360**, **370**, **380**, **390**, **395**, **396**, **397**, and **398** supporting DGTaskExecutor, according to some example embodiments. DGTaskExecutor **310** is shown to be built on Resource Manager **320**, Task Graph **390**, Priority Recalculator **380**, and Thread Manager **360**.

Resource Manager **320** manages Resource Queue **330**, which is supported by Ranked Priority Queue **340** and Resource Configuration Provider **342**. Ranked Priority Queue **340** and Resource Configuration Provider **342** are supported by Resource Constraint **350**. Priority Recalculator **380** is supported by Task Graph **390** and Priority Provider **395**, which provides an interface (e.g., a pluggable interface) for scoring algorithms to be created. In some example embodiments, three types of priority algorithms are supported: Null **396**, Static **397**, and Dynamic **398**.

A ranked priority queue (e.g., Ranked Priority Queue **340**) is a data structure (e.g., a priority queue or a heap) that may allow for random access, which may be an efficient way to access the data structure. The ranked priority queue allows a value (e.g., a rank) of a node to change independently of the value used to rank the queue. In the context of concurrent execution of tasks, the ranked priority feature results in a valid ordering of the queue, even though a rank of a given node may be changing. Changes to priority may be "published" to the ranked priority queue at a later time, after which a DGTaskExecutor system fetches a new rank and readjusts the queue with respect to priority.

A resource constraint class (e.g., Resource Constraint **350**) may define a type of constraint on a data processing resource. For example, the type may be "fixed" (e.g., with a fixed number of data processing resources) or "unbounded" (e.g., with no constraint).

A resource queue class (e.g., Resource Queue **330**) may manage a number of data processing resources available with respect to a given data processing resource. Tasks stored within this class (e.g., task in queue) may be stored in priority order, so that a task with a highest priority will have the first chance to utilize a given data processing resource. The resource queue class may be built upon the ranked priority queue class and the resource constraint class.

A resource manager class (e.g., Resource Manager **320**) may manage one or more data processing resources, one or more resource queries (e.g., queries regarding capacity, constraints, or status of a data processing resource), one or more executable tasks, or any suitable combination thereof. In some example embodiments, the resource manager class is implemented as a group of resource queue classes.

A resource configuration provider class (e.g., Resource Configuration Provider **342**) manages the set of resource constraints that exist within the system. This class allows for both the modification of resource constraints within the system at runtime as well as providing a base configuration/implementation that can be overridden at compile time.

A priority provider class (e.g., Priority Provider **395**) may calculate an additional priority to be added to a given task. In some example embodiments, DGTaskExecutor **310** supports three types. In these example embodiments, null priority (e.g., Null **396**) always has a value of zero, such that all tasks in the dependency model have equal priority. Static priority (e.g., Static **397**) always has a value of one. The priority of a task may be equal to a number of children that are dependent on the task. Dynamic priority (e.g., Dynamic **398**) may vary based on the structure of a task graph. For example, the priority that tasks pass to parent tasks may degrade in a consistent fashion depending on position of the task in the dependency model (e.g., closer to the root node where no further parent tasks exist). Dynamic priority may prioritize execution of tasks based on the structure of a task graph and may favor sets of tasks that have wide dependency models with many parallelizable tasks.

A thread configuration provider class (e.g., Thread Configuration Provider **370**) may provide a thread configuration to the Thread Manager **360**, which manages threads (e.g., in conjunction with the Priority Recalculator **380** and the Resource Manager **320**).

A priority recalculator class (e.g., Priority Recalculator **380**) may recalculate a priority added to a dependency model by a dependency (e.g., a newly added dependency from a newly added task). For example, the priority recalculator class may add additional priority to each parent task of a newly added task.

A task graph class (e.g., Task Graph **390**) may allow a software application to describe a dependency model (e.g., task graph). Analysis of the dependency model may be performed by a DGTaskExecutor system to adjust the priority of one or more nodes within the dependency model, as well as to detect deadlocks. The task graph class may store representations of one or more child nodes of a task. These child nodes may be used to find further tasks that may become executable. The task graph class may facilitate finding tasks. Moreover, the task graph class may facilitate loading or storing intermediate task results based on a task identifier of a task. In general, the task graph class may manage the set of tasks that have been registered with DGTaskExecutor **310**.

Moreover, a task manager class (not shown) may provide an internal façade for the whole task executor. The task manager class may facilitate one or more user-facing activities (e.g., managing addition of tasks to the dependency model, managing when dynamic prerequisites should be fetched, how joins are managed, or deadlock detection) and may be built upon a priority recalculator class (e.g., Priority Recalculator **380**), a task graph class (e.g., Task Graph **390**), a resource manager class (e.g., Resource Manager **320**), or any suitable combination thereof.

The DGTaskExecutor **310** class may support an external interface (e.g., a class) for accessing DGTaskExecutor (the system, the method, or both) through utilization of the task manager class to provide DGTaskExecutor services.

FIG. **4** is a network diagram illustrating a network environment **400**, according to some example embodiments. The network environment **400** is shown to include a software application server machine **410** and software application client machines **430**, **440**, and **450**, all coupled to each other via a network **420**.

Any of the machines shown in FIG. **4** may be implemented in a general-purpose computer modified (e.g., configured or programmed) by software to be a special-purpose computer to perform the functions described herein for that machine. For example, a computer system able to implement any one or more of the methodologies described herein is discussed below with respect to FIG. **12**, below. Moreover, any two or more of the machines illustrated in FIG. **4** may be combined into a single machine, and the functions described herein for any single machine may be subdivided among multiple machines.

The network **420** may be any network that enables communication between machines (e.g., the software application server machine **410** and the software application client machine **430**). Accordingly, the network **420** may be a wired network, a wireless network, or any suitable combination thereof. The network **420** may include one or more portions that constitute a private network, a public network (e.g., the Internet), or any suitable combination thereof.

FIG. **5** is a block diagram of the software application server machine **410**, according to some example embodiments. The software application server machine **410** is shown to include a task module **510**, a dependency module **520**, a generation module **530**, a schedule module **540**, and a document module **550**, all coupled (e.g., configured) to communicate with each other (e.g., via a bus, a shared memory, or a switch). Any of these modules may be implemented using hardware or a combination of hardware and software. Moreover, any two or more of these modules may be combined into a single module, and the functions described herein for a single module may be subdivided among multiple modules.

FIG. **6-11** are flowcharts illustrating operations in a method **600** of dependency-based task scheduling, according to some example embodiments. FIG. **6** illustrates a simple example of the method **600**. FIG. **7-11** illustrate various optional or alternative paths of the method **600**.

As shown in FIG. **6**, the method **600** includes:

identifying **610** a set of tasks as being requested for execution, with the set of tasks including a first task and a second task;

accessing **620** task dependency data of the second task (e.g., from a cache), with the task dependency data indicating that the first task is to be executed prior to the second task;

generating **630** dependency model data of the set of tasks based on the task dependency data, with the dependency model data indicating that the first task is to be executed prior to the second task, and the generating of the dependency model data being performed by a processor of a machine; and

scheduling **640** an execution of the first task using a data processing resource based on the dependency model data, with the first task being scheduled for execution using the data processing resource prior to an execution of the second task. Scheduling **650** of another task is discussed below.

The identifying **610** may be performed by the task module **510**. The accessing **620** may be performed by the dependency module **520**. The generating **630** may be performed by the generation module **530**. The scheduling **640** may be performed by the schedule module **540**.

Moreover, as shown in FIG. **7**, the method **600** may include:

accessing **710** resource data of the data processing resource; and

scheduling **730** an execution of a third task of the plurality of tasks, with the third task being scheduled for execution by the data processing resource prior to the execution of the first task; wherein:

the generating of the dependency model data **630** is further based on the resource data and includes determining **720** that a third task of the plurality of tasks is to be executed prior to the first task; and

the dependency model data indicates that the third task is to be executed prior to the first task.

The accessing **710** may be performed by the dependency module **520**. The determining **720** may be performed by the generation module **530**. The scheduling **730** may be performed by the schedule module **540**.

In some example embodiments, the resource data indicates at least one of a capability of the data processing resource or a constraint on the data processing resource.

In certain example embodiments, the data processing resource is at least one of a hardware resource, a software resource, a network resource, or a service resource.

In various example embodiments, the data processing resource is at least one of a database connection or the processor of the machine.

As shown in FIG. **8**, the method **600** may include detecting **810** an indication that a third task of the set of tasks has been executed. In some situations, the generating of the dependency model data includes updating **820** the dependency model data in response to the indication, with the updating of the dependency model data being based on further task dependency data of the third task. The detecting **810** may be performed by the dependency module **520**. The updating **820** may be performed by the generation module **530**.

As shown in FIG. **9**, the method **600** may include determining **910** that a condition pertinent to the first task has been satisfied, with the condition being pertinent to the execution of the first task prior to the execution of the second task. In certain situations, the identifying **610** of the plurality of tasks includes adding **940** the first task to a further plurality of tasks that includes the second task. The determining **910** may be performed by the task module **510**. The adding **940** may be performed by the task module **510**.

FIG. **9** further illustrates that method **600** may include: determining **920** that a further task is to be added to the set of tasks, with the determining being performed during at least one of the execution of the first task or the execution of the second task; and adding **940** the further task to the set of tasks. The determining **920** may be performed by the task module **510**.

Still referring to FIG. **9**, the method **600** may include: accessing **930** further task dependency data of the further task, with the further task dependency data indicating that the further task is to be executed after at least one of the execution of the first task of the execution of the second task; and updating the dependency model data based on the further task dependency data. The accessing **930** may be performed by the task module **510**.

As shown in FIG. **10**, the method **600** may include determining **1020** that the dependency model data is devoid of information indicating that the second task is to be executed prior the first task. The determining **1020** may be performed by the generation module **530**.

FIG. **10** further illustrates that the method **600** may include receiving **1010** a request that a document be provided to a user, with the document including a portion definable by information resultant from the execution of the first task. In some situations, the identifying **610** of the set of tasks is in response to the request. The receiving **1010** may be performed by the task module **510**.

According to some example embodiments, the document corresponds to a network-based locator; the request includes the network-based locator; and the document module is configured to generate the document based on the information resultant from the execution of the first task.

Still referring to FIG. **10**, the method **600** may include providing **1030** the portion of the document to the user after the execution of the first task and during the execution of the second task. In various situations, a further portion of the document is definable by further information resultant from the execution of the second task. The providing **1030** may be performed by the document module **550**.

Returning to FIG. **6**, the method **600** may include scheduling **650** an execution of a third task of the set of tasks, with the execution of the third task being scheduled as contemporaneous with the execution of the first task. The scheduling **650** may be performed by the schedule module **540**.

As shown in FIG. **11**, the method **600** may include:

obtaining **1120** information resultant from the execution of the first task;

generating **1130** a portion of the document based on the information resultant from the execution of the first task; and

providing **1140** the portion of the document in response to a request that identifies a URL of the document.

The obtaining **1120** may be performed by the document module **550**. Moreover, the generating **1130** may be performed by the document module **550**. Furthermore, the providing **1140** may be performed by the document module **550**.

According to certain example embodiments, the first task is defined by a data structure and includes an instruction to perform at least one of the retrieval of data from a database or a conversion of the data.

In some example embodiments, the second task is defined by a data structure that includes the task dependency data.

Still referring to FIG. **11**, the method **600** may include executing **1110** the first task using the data processing resource. The executing **1110** may be performed by the document module **550**.

According to various example embodiments, one or more of the methodologies described herein may facilitate the scheduling or execution of tasks. In particular, where information regarding dependencies among tasks is available (e.g., as task dependency data corresponding to one or more tasks), one or more of the methodologies discussed herein may facilitate full or partial optimizations in task scheduling and task execution. Accordingly, one or more of the methodologies discussed herein may obviate a need for single-threaded implementation of the software application (e.g., execution of only one task at a time), which may have one or more technical effects. Examples of technical effects include: enhancing performance of the software application, reducing completion time for execution of tasks corresponding to the software application, and reducing user wait time for provision of a requested document.

FIG. **12** illustrates components of a machine **1200**, according to some example embodiments, that is able to read instructions from a machine-readable medium (e.g., a non-transitory machine-readable storage medium) and perform any one or more of the methodologies discussed herein. Specifically, FIG. **12** shows a diagrammatic representation of the machine **1200** in the example form of a computer system and within which instructions **1224** (e.g., software) for causing the machine **1200** to perform any one or more of the methodologies discussed herein may be executed. In alternative embodiments, the machine **1200** operates as a standalone device or may be connected (e.g., networked) to other machines. In a networked deployment, the machine **1200** may operate in the capacity of a server machine or a client machine in a server-client network environment, or as a peer machine in a peer-to-peer (or distributed) network environment. The machine **1200** may be a server computer, a client computer, a personal computer (PC), a tablet computer, a laptop computer, a netbook, a set-top box (STB), a personal digital assistant (PDA), a cellular telephone, a smartphone, a web appliance, a network router, a network switch, a network bridge, or any machine capable of executing the instructions **1224** (sequentially or otherwise) that specify actions to be taken by that machine. Further, while only a single machine is illustrated, the term "machine" shall also be taken to include a collection of machines that individually or jointly execute the instructions **1224** to perform any one or more of the methodologies discussed herein.

The machine **1200** is shown to include a processor **1202** (e.g., a central processing unit (CPU), a graphics processing unit (GPU), a digital signal processor (DSP), an application specific integrated circuit (ASIC), a radio-frequency integrated circuit (RFIC), or any suitable combination thereof), a main memory **1204**, and a static memory **1206**, which are configured to communicate with each other via a bus **1208**. The machine **1200** may further include a graphics display **1210** (e.g., a plasma display panel (PDP), a liquid crystal display (LCD), a projector, or a cathode ray tube (CRT)). The machine **1200** may also include an alphanumeric input device **1212** (e.g., a keyboard), a cursor control device **1214** (e.g., a mouse, a touchpad, a trackball, a joystick, a motion sensor, or other pointing instrument), a storage unit **1216**, a signal generation device **1218** (e.g., a speaker), and a network interface device **1220**.

The storage unit **1216** includes a machine-readable medium **1222** on which is stored the instructions **1224** (e.g., software) embodying any one or more of the methodologies or functions described herein. The instructions **1224** may also reside, completely or at least partially, within the main memory **1204**, within the processor **1202** (e.g., within the processor's cache memory), or both, during execution thereof by the machine **1200**. Accordingly, the main memory **1204** and the processor **1202** may be considered as machine-readable media. The instructions **1224** may be transmitted or received over a network **1226** (e.g., network **420**) via the network interface device **1220**.

As used herein, the term "memory" refers to a machine-readable medium able to store data temporarily or permanently and may be taken to include, but not be limited to, random-access memory (RAM), read-only memory (ROM), buffer memory, flash memory, and cache memory. While the machine-readable medium **1222** is shown in an example embodiment to be a single medium, the term "machine-readable medium" should be taken to include a single medium or multiple media (e.g., a centralized or distributed database, or associated caches and servers) able to store instructions (e.g., instructions **1224**). The term "machine-readable medium" shall also be taken to include any medium that is capable of storing instructions (e.g., software) for execution by the machine, such that the instructions, when executed by one or more processors of the machine (e.g., processor **1202**), cause the machine to perform any one or more of the methodologies described herein. The term "machine-readable medium" shall accordingly be taken to include, but not be limited to, a data repository in the form of a solid-state memory, an optical medium, a magnetic medium, or any suitable combination thereof.

Throughout this specification, plural instances may implement components, operations, or structures described as a single instance. Although individual operations of one or more methods are illustrated and described as separate operations, one or more of the individual operations may be performed concurrently, and nothing requires that the operations be performed in the order illustrated. Structures and functionality presented as separate components in example configurations may be implemented as a combined structure or component. Similarly, structures and functionality presented as a single component may be implemented as separate components. These and other variations, modifications, additions, and improvements fall within the scope of the subject matter herein.

Certain embodiments are described herein as including logic or a number of components, modules, or mechanisms. Modules may constitute either software modules (e.g., code embodied on a machine-readable medium or in a transmission signal) or hardware modules. A "hardware module" is a tangible unit capable of performing certain operations and may be configured or arranged in a certain physical manner. In various example embodiments, one or more computer systems (e.g., a standalone computer system, a client computer system, or a server computer system) or one or more hardware modules of a computer system (e.g., a processor or a group of processors) may be configured by software (e.g., an application or application portion) as a hardware module that operates to perform certain operations as described herein.

In some embodiments, a hardware module may be implemented mechanically, electronically, or any suitable combination thereof. For example, a hardware module may include dedicated circuitry or logic that is permanently configured to perform certain operations. For example, a hardware module may be a special-purpose processor, such as a field programmable gate array (FPGA) or an application-specific integrated circuit (ASIC). A hardware module may also include programmable logic or circuitry that is temporarily configured by software to perform certain operations. For example, a hardware module may include software encompassed within a general-purpose processor or other programmable processor. It will be appreciated that the decision to implement a hardware module mechanically, in dedicated and permanently configured circuitry, or in temporarily configured circuitry (e.g., configured by software) may be driven by cost and time considerations.

Accordingly, the term "hardware module" should be understood to encompass a tangible entity, be that an entity that is physically constructed, permanently configured (e.g., hardwired), or temporarily configured (e.g., programmed) to operate in a certain manner or to perform certain operations described herein. As used herein, "hardware-implemented module" refers to a hardware module. Considering embodiments in which hardware modules are temporarily configured (e.g., programmed), each of the hardware modules need not be configured or instantiated at any one instance in time. For example, where the hardware modules comprise a general-purpose processor configured by software to become a special-purpose processor, the general-purpose processor may be configured as respectively different hardware modules at different times. Software may accordingly configure a processor, for example, to constitute a particular hardware module at one instance of time and to constitute a different hardware module at a different instance of time.

Hardware modules can provide information to, and receive information from, other hardware modules. Accordingly, the described hardware modules may be regarded as being communicatively coupled. Where multiple hardware modules exist contemporaneously, communications may be achieved through signal transmission (e.g., over appropriate circuits and buses) between or among two or more of the hardware modules. In embodiments in which multiple hardware modules are configured or instantiated at different times, communications between such hardware modules may be achieved, for example, through the storage and retrieval of information in memory structures to which the multiple hardware modules have access. For example, one hardware module may perform an operation and store the output of that operation in a memory device to which it is communicatively coupled. A further hardware module may then, at a later time, access the memory device to retrieve and process the stored output. Hardware modules may also initiate communications with input or output devices, and can operate on a resource (e.g., a collection of information).

The various operations of example methods described herein may be performed, at least partially, by one or more processors that are temporarily configured (e.g., by software) or permanently configured to perform the relevant operations. Whether temporarily or permanently configured, such processors may constitute processor-implemented modules that operate to perform one or more operations or functions described herein. As used herein, "processor-implemented module" refers to a hardware module implemented using one or more processors.

Similarly, the methods described herein may be at least partially processor-implemented, a processor being an example of hardware. For example, at least some of the operations of a method may be performed by one or more processors or processor-implemented modules. Moreover, the one or more processors may also operate to support performance of the relevant operations in a "cloud computing" environment or as a "software as a service" (SaaS). For example, at least some of the operations may be performed by a group of computers (as examples of machines including processors), with these operations being accessible via a network (e.g., the Internet) and via one or more appropriate interfaces (e.g., an application program interface (API)).

The performance of certain of the operations may be distributed among the one or more processors, not only residing within a single machine, but deployed across a number of machines. In some example embodiments, the one or more processors or processor-implemented modules may be located in a single geographic location (e.g., within a home environment, an office environment, or a server farm). In other example embodiments, the one or more processors or processor-implemented modules may be distributed across a number of geographic locations.

Some portions of this specification are presented in terms of algorithms or symbolic representations of operations on data stored as bits or binary digital signals within a machine memory (e.g., a computer memory). These algorithms or symbolic representations are examples of techniques used by those of ordinary skill in the data processing arts to convey the substance of their work to others skilled in the art. As used herein, an "algorithm" is a self-consistent sequence of operations or similar processing leading to a desired result. In this context, algorithms and operations involve physical manipulation of physical quantities. Typically, but not necessarily, such quantities may take the form of electrical, magnetic, or optical signals capable of being stored, accessed, transferred, combined, compared, or otherwise manipulated by a machine. It is convenient at times, principally for reasons of common usage, to refer to such signals using words such as "data," "content," "bits," "values," "elements," "symbols," "characters," "terms," "numbers," "numerals," or the like. These words, however, are merely convenient labels and are to be associated with appropriate physical quantities.

Unless specifically stated otherwise, discussions herein using words such as "processing," "computing," "calculating," "determining," "presenting," "displaying," or the like may refer to actions or processes of a machine (e.g., a computer) that manipulates or transforms data represented as physical (e.g., electronic, magnetic, or optical) quantities within one or more memories (e.g., volatile memory, non-volatile memory, or any suitable combination thereof), registers, or other machine components that receive, store, transmit, or display information. Furthermore, unless specifically stated otherwise, the terms “a” or “an” are herein used, as is common in patent documents, to include one or more than one instance. Finally, as used herein, the conjunction “or” refers to a non-exclusive “or,” unless specifically stated otherwise.

What is claimed is:

1. A method comprising:

accessing dependency model data of a plurality of tasks, the plurality of tasks including a first task and a second task, the dependency model data indicating dependencies between the plurality of tasks and a priority of each of the plurality of tasks;

scheduling an execution order of the plurality of tasks such that the first task is scheduled to execute before the second task;

receiving a request to add a third task to the dependency model;

based on the request, creating, by a processor of a machine, an updated dependency model corresponding to the third task and the plurality of tasks, the updated dependency model indicating a dependency of the third task on the second task;

updating the priority of the second task based on the dependency of the third task on the second task; and

responsive to the updating of the priority of the second task, adjusting the scheduled execution order of the plurality of tasks such that the second task is scheduled to execute before the first task.

2. The method of claim **1**, wherein:

the scheduling the execution order of the plurality of tasks schedules a fourth task to execute before the second task, based on the priority of the second task and the priority of the fourth task.

3. The method of claim **1**, wherein:

the updating of the priority of the second task is further based on the dependency model data of the second task.

4. The method of claim **1**, further comprising:

detecting an indication that a fourth task of the plurality of tasks has been executed; and

in response to the detecting of the indication, creating a further updated dependency model based on task dependency data of the fourth task.

5. The method of claim **1**, further comprising:

determining that a fourth task is to be added to the plurality of tasks, the determining being performed during execution of at least one of the first task or the second task; and

adding the fourth task to the plurality of tasks.

6. The method of claim **5**, further comprising:

accessing task dependency data of the fourth task, the task dependency data indicating that the fourth task is to be executed after at least one of the execution of the first task or the execution of the second task; and

based on the task dependency data of the fourth task, creating a further updated dependency model corresponding to the first task, the fourth task, and the plurality of tasks.

7. A system comprising:

a processor of a machine;

wherein the processor of the machine performs the steps of:

a dependency module configured to access dependency model data of a plurality of tasks, the plurality of tasks including a first task and a second task, the dependency model data indicating dependencies between the plurality of tasks and a priority of each of the plurality of tasks;

a schedule module configured to:

schedule an execution order of the plurality of tasks such that the first task is scheduled to execute before the second task; and

a task module configured to receive a request to add a third task to the dependency model;

the dependency module being further configured to:

based on the request, create an updated dependency model corresponding to the third task and the plurality of tasks, the updated dependency model indicating a dependency of the third task on the second task and

update the priority of the second task based on the dependency of the third task on the second task;

the schedule module being further configured to:

responsive to the updating of the priority of the second task, adjust the scheduled execution order of the plurality of tasks such that the second task is scheduled to execute before the first task.

8. The system of claim **7**, wherein:

the scheduling the execution order of the plurality of tasks schedules a fourth task to execute before the second task, based on the priority of the second task and the priority of the fourth task.

9. The system of claim **7**, wherein:

the updating of the priority of the second task is further based on the dependency model data of the second task.

10. The system of claim **7**, wherein:

the task module is further configured to:

detect an indication that a fourth task of the plurality of tasks has been executed; and

the dependency module is further configured to:

in response to the detection of the indication, create a further updated dependency model based on task dependency data of the fourth task.

11. The system of claim **7**, wherein the task module is further configured to:

determine that a fourth task is to be added to the plurality of tasks during execution of at least one of the first task or the second task; and

add the fourth task to the plurality of tasks.

12. The system of claim **11**, wherein the dependency module is further configured to:

access task dependency data of the fourth task, the task dependency data indicating that the fourth task is to be executed after at least one of the execution of the first task or the execution of the second task; and

based on the task dependency data of the fourth task, create a further updated dependency model corresponding to the first task, the fourth task, and the plurality of tasks.

13. A non-transitory machine-readable storage medium comprising instructions that, in response to execution by a machine, cause the machine to perform operations comprising:

accessing dependency model data of a plurality of tasks, the plurality of tasks including a first task and a second task, the dependency model data indicating dependencies between the plurality of tasks and a priority of each of the plurality of tasks;

scheduling an execution order of the plurality of tasks such that the first task is scheduled to execute before the second task;

receiving a request to add a third task to the dependency model;

based on the request, creating an updated dependency model corresponding to the third task and the plurality of tasks, the updated dependency model indicating a dependency of the third task on a second task;

updating the priority of the second task based on the dependency of the third task on the second task; and

responsive to the updating of the priority of the second task, adjusting the scheduled execution order of the plurality of tasks such that the second task is scheduled to execute before the first task.

14. The non-transitory machine-readable medium of claim **13**, wherein:

the scheduling the execution order of the plurality of tasks schedules a fourth task to execute before the second task, based on the priority of the second task and the priority of the fourth task.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : 9,223,628 B2
APPLICATION NO. : 14/509936
DATED : December 29, 2015
INVENTOR(S) : Perv Rastogi

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

On the title page, in column 2, under “Other Publications”, line 5, Delete “13/166,395. ● Non” and insert --13/166,395, Non--, therefor

Signed and Sealed this
Nineteenth Day of April, 2016

Michelle K. Lee

Michelle K. Lee
Director of the United States Patent and Trademark Office